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Title: Use of Satellite Data and Modeling to Assess the Influence of Stratospheric Processes on the Troposphere

Principal Investigator:

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Significant Accomplishments in the Past Year (1989-1990)

1. Barotropic instability of realistic zonally varying flows in the stratosphere: a possible mechanism for the origin of free planetary waves observed in satellite data.

A variety of waves exist in the stratosphere whose origin and mechanisms governing their life cycles are poorly understood. The difficulty stems, in part, from the fact that many interrelated nonlinear physical and dynamical processes are involved in their evolution. To shed further light on the possible origin of such features as the "two-day" mesospheric wave and the short-period, long-lived disturbances observed in satellite data in the polar winter stratosphere, we have examined the stability of *time dependent zonally varying flow* using nondivergent barotropic models on a sphere. The basic states used in the models were based on idealized flows, and on realistic flows that were constructed from satellite data. Details concerning this work can be found in Manney, Nathan and Stanford (1989) and Manney and Nathan (1990).

Briefly, we have shown that for a basic state consisting of a realistic zonal jet and a travelling wave, coherent disturbances characterized by a multimode zonal wave spectrum emerge which move with the basic state wave. These disturbances may be related to the quasi-nondispersive features observed in satellite data in the polar winter stratosphere (Lait and Stanford, 1988; *JAS*). We also have examined the stability of a basic state that is composed of a westward-moving wave and a zonal mean jet. The sensitivity of the flow stability to the strength and structure of the zonal jet was emphasized. We found that for a basic state resembling the observed "two-day" wave, inclusion of an easterly (summer) jet in the basic state has a srong stabilizing influence. When a *strong* easterly jet is included in the basic state, unstable disturbances occur that have structures similar to waves observed concurrently with the two-day wave. Evidence was also presented showing a seasonal dependence in the stability of several westward moving basic state waves.

2. Stability of simple models of the earth system: interactions among radiation, photochemistry, and dynamics.

Over the years, numerous studies have examined the stability of atmospheric flows to planetary and synoptic-scale perturbations. Nevertheless, our understanding of the mechanism(s) responsible for the birth, evolution, and eventual demise of such waves is clearly inadaquate. To provide a better understanding of how ozone can affect planetary waves, Nathan (1989) examined analytically the linear stability of free planetary waves in the presence of radiative-photochemical feedbacks in a continuously stratified, extratropical baroclinic model of the atmosphere. The flow was described by *coupled* equations for the quasigeostrophic potential vorticity and ozone volume mixing ratio. It was shown that radiative-photochemical feedbacks can destabilize free planetary waves. The expression for the growth rate was obtained in terms of the vertically averaged wave

activity, and depends on three distinct processes: i) meridional advection of basic state ozone, ii) vertical advection of basic state ozone, and iii) photochemically accelerated cooling. For waves whose peak amplitudes are in the lower stratosphere, vertical ozone advection dominates and is destabilizing. Extensions of this work to climatological and realistic instantaneous basic state wind, temperature, and ozone profiles has been initiated.

Focus of Current Research

Our current research is focused on the following problems:

1. *Examination of the effects of ozone heating and Newtonian cooling on the linear stability of transient planetary waves.* A finite difference numerical model was developed in which the basic state wind, temperature, and ozone distributions were constructed using ground-based and satellite data. Preliminary results indicate that ozone dynamics interaction may play a more important role in the stability and maintenance of planetary waves than previouly thought, particularly in summer when the mean solar zenith angle is smallest and thus ozone heating largest.
2. *Examination of the finite amplitude interactions among radiation, ozone, and dynamics.* Self-consistent, coupled equations governing the weakly nonlinear interactions between the ozone and streamfunction fields has been derived. These equations are currently being analyzed to provide a better understanding of wave-mean flow interactions and ozone transport in a continuously stratified model of the troposphere-stratosphere coupled system.

Plans for Next Year

A new proposal has been submitted to NASA. This proposal forms a logical and significant extension of work carried out by the PI and his graduate students under the current NASA grant, which is scheduled to end in January 1991. The goal is to carry out a comprehensive, multifaceted analysis of the *combined* physical processes that generate, maintain, and damp planetary-scale waves at middle latitudes. Attention will be focused on those components of the earth system that combine the diabatic processes generated by internal radiative-photochemical feedbacks and external periodic (seasonal) forcing with the large-scale circulation of the atmosphere. To carry out the research, analytical and numerical models of the troposphere-stratosphere coupled system in beta-plane and spherical geometries will be used in conjunction with ground-based and satellite data.

Refereed Publications (1989-1990)

1. Nathan, T. R., 1989: On the role of dissipation in the finite amplitude interactions between forced and free baroclinic waves. *Geophys. Astro. Fluid Dyn.*, **45**, 17 pgs.
2. Manney, G. L., T. R. Nathan, and J. L. Stanford, 1989: Barotropic instability of basic states with a realistic jet and a wave. *J. Atmos. Sci.*, **46**, 13 pgs..
3. Nathan, T. R., 1989: On the role of ozone in the stability of Rossby normal modes. *J. Atmos. Sci.*, **46**, 6 pgs.
4. Manney, G. L., and T. R. Nathan, 1990: Barotropic instability of westward-moving waves in realistic stratospheric zonal flows. *J. Atmos. Sci.*, **47**, 19 pgs.
5. Howell, P., and T. R. Nathan, 1990: Barotropic instability of zonally varying flow forced by multimode topography. *Dyn. Atmos. Oceans.* (in press)
6. Nathan, T. R., and L. Li, 1990: Effects of ozone and Newtonian cooling on the linear stability of transient planetary waves. (To be submitted to *J. Atmos Sci.*)

Additional Personnel Involved in the Project

Dr. Gloria Manney (Completed Ph.D. in 1988. Dr. Manney is currently a National Research Council Post Doctorate Fellow at the Jet Propulsion Laboratory.)

Mr. Paul Howell (Completed M.S. in 1989. Thesis title: A simple model of barotropic instability of flow forced by multimode topography.)

Ms. Cathy Hamann (M.S. expected in 1990. Thesis title: Linear and nonlinear stability of zonally varying flow.)

Mr. Long Li (M.S. expected in 1990. Thesis title: Effects of ozone heating and Newtonian cooling on the stability of transient planetary waves.)